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Updated Galileo probe mass spectrometer measurements of carbon, oxygen, nitrogen, and sulfur on Jupiter

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Abstract

The in situ measurements of the Galileo Probe Mass Spectrometer (GPMS) were expected to constrain the abundances of the cloud-forming condensible volatile gases: H_2O, H_2S, and NH_3. However, since the probe entry site (PES) was an unusually dry meteorological system—a 5-μm hotspot—the measured condensible volatile abundances did not follow the canonical condensation-limited vertical profiles of equilibrium cloud condensation models (ECCMs) such as Weidenschilling and Lewis (1973, Icarus 20, 465–476). Instead, the mixing ratios of H_2S and NH_3 increased with depth, finally reaching well-mixed equilibration levels at pressures far greater than the lifting condensation levels, whereas the mixing ratio of H_2O in the deep well-mixed atmosphere could not be measured. The deep NH_3 mixing ratio (with respect to H_2) of $(6.64 \pm 2.54) \times 10^{-4}$ from 8.9–11.7 bar GPMS data is consistent with the NH_3 profile from probe-to-orbiter signal attenuation (Folkner et al., 1998, J. Geophys. Res. 103, 22847–22856), which had an equilibration level of about 8 bar. The GPMS deep atmosphere H_2S mixing ratio of $(8.9 \pm 2.1) \times 10^{-5}$ is the only measurement of Jupiter's sulfur abundance, with a PES equilibration level somewhere between 12 and 15.5 bar. The deepest water mixing ratio measurement is $(4.9 \pm 1.6) \times 10^{-4}$ (corresponding to only about 30% of the solar abundance) at 17.6–20.9 bar, a value that is probably much smaller than Jupiter's bulk water abundance. The $^{15}N/^{14}N$ ratio in jovian NH_3 was measured at $(2.3 \pm 0.3) \times 10^{-3}$ and may provide the best estimate of the protosolar nitrogen isotopic ratio. The GPMS methane mixing ratio is $(2.37 \pm 0.57) \times 10^{-3}$; although methane does not condense on Jupiter, we include its updated analysis in this report because like the condensible volatiles, it was presumably brought to Jupiter in icy planetesimals. Our detailed discussion of calibration and error analysis supplements previously reported GPMS measurements of condensible volatile mixing ratios (Niemann et al., 1998, J. Geophys. Res. 103, 22831–22846; Atreya et al., 1999, Planet. Space Sci. 47, 1243–1262; Atreya et al., 2003, Planet. Space Sci. 51, 105–112) and the nitrogen isotopic ratio (Owen et al., 2001b, Astrophys. J. Lett. 553, L77–L79). The approximately three times solar abundance of NH_3 (along with CH_4 and H_2S) is consistent with enrichment of Jupiter's atmosphere by icy planetesimals formed at temperatures < 40 K (Owen et al., 1999, Nature 402 (6759), 269–270), but would imply that H_2O should be at least $3 \times$ solar as well. An alternate model, using clathrate hydrates to deliver the nitrogen component to Jupiter, predicts $O/H \geqslant 9 \times$ solar (Gautier et al., 2001, Astrophys. J. 550 (2), L227–L230). Finally we show that the measured condensible volatile vertical profiles in the PES are consistent with column-stretching or entraining downdraft scenarios *only* if the basic state (the pre-stretched column or the entrainment source region) is described by condensible volatile vertical profiles that are drier than those in the equilibrium cloud condensation models. This dryness is supported by numerous remote sensing results but seems to disagree with observations of widespread clouds on Jupiter at pressure levels predicted by equilibrium cloud condensation models for ammonia and H_2S.

Keywords: Jupiter, atmosphere; Atmospheres, composition; Galileo probe

1. Introduction

The Galileo probe's in situ measurements provided a unique opportunity to sample Jupiter's atmosphere below

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